Attribution of a changing evaporation regime:

Identifying three distinct responses within the Horn of Africa bimodal rainfall region

Toby Marthews, Friedericke Otto, Daniel Mitchell, Simon J. Dadson, Richard Jones, Myles Allen

www.TobyMarthews.com

Oxford, 12th September 2017

CEH updates: @CEHScienceNews

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The ACE-Africa project

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Drought forecasted in Jun 2014.

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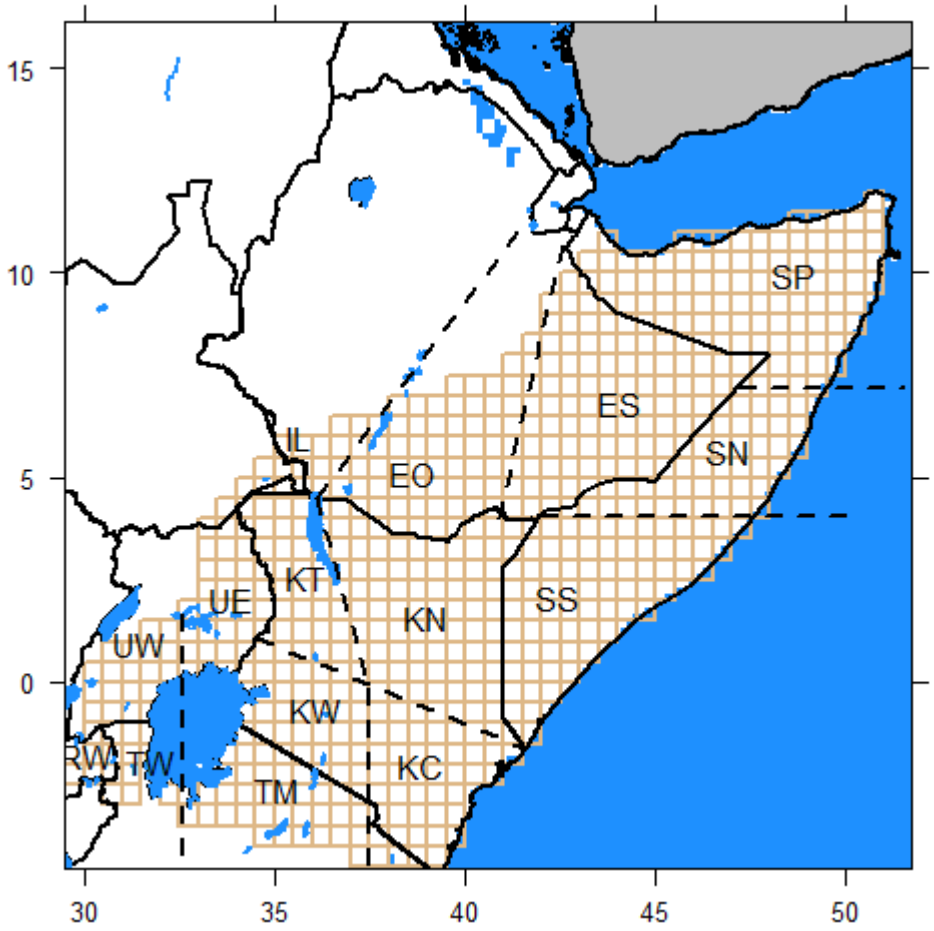
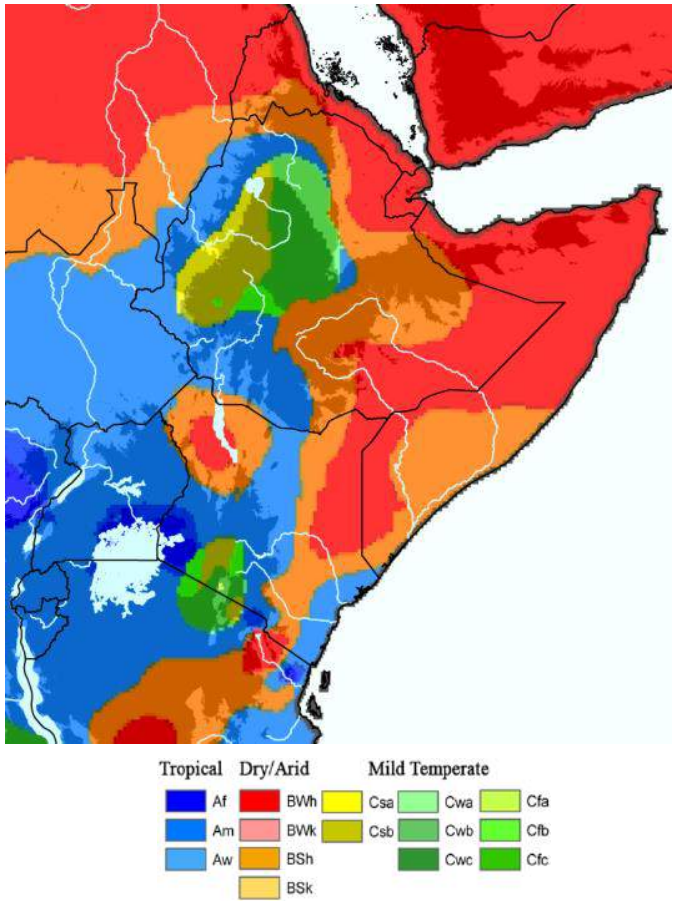
The Horn of Africa bimodal rainfall region



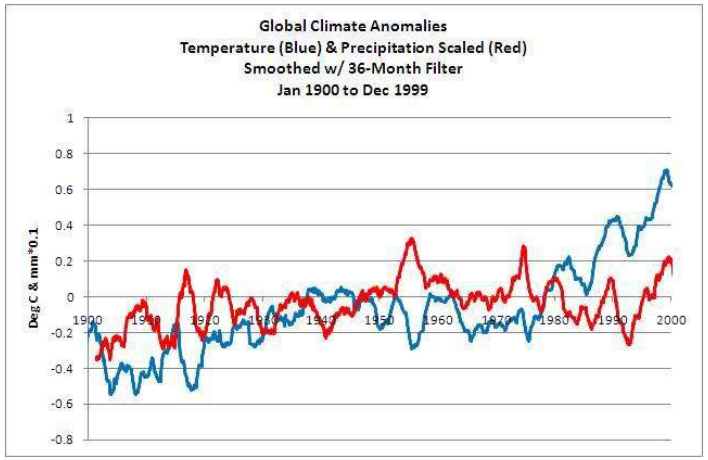


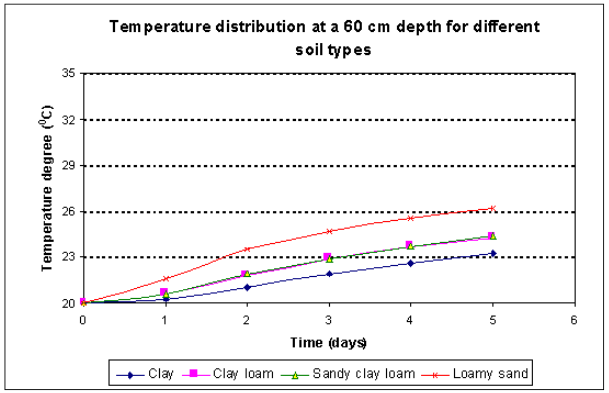
Gridded area = the zone of bimodal rainfall in this area of Africa (the ‘long rains’ March to May and the ‘short rains’ October to December) from TAMSAT data 1983-2012.

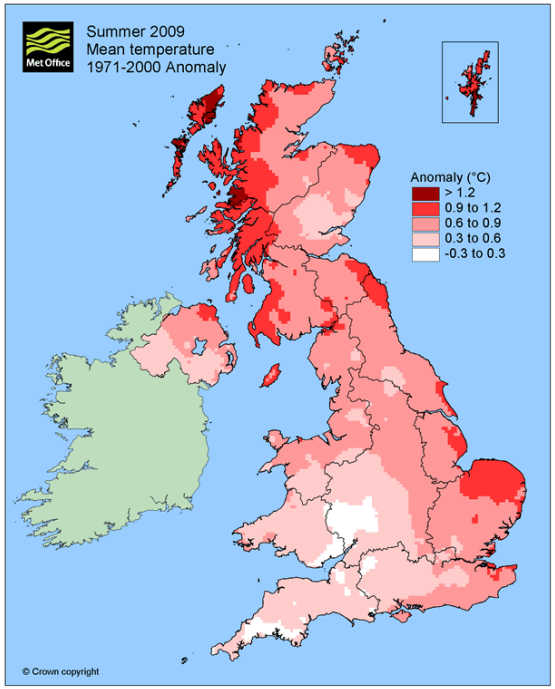
Right: Köppen-Geiger arid and semi-arid zones

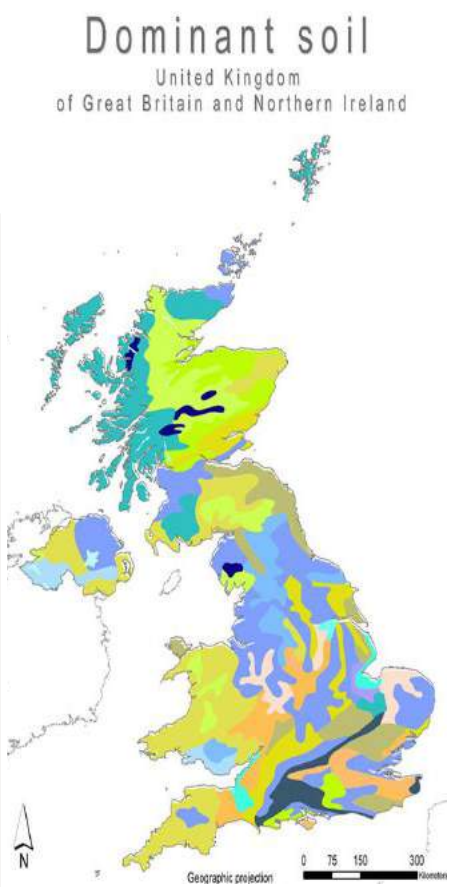
A concept of field capacity for drought dry-down

"*After heavy rain, a surface T anomaly map looks exactly like a precipitation anomaly map, but after a while it looks like a soil map*" (E. Blyth, CEH). How true is this?









We would expect the first part to be true at large spatial scales at least (top left). Also, we know that temperature trajectories differ by soil type over time in local studies (lower left), even though at medium scales T anomalies don't seem to converge exactly to a soil map (UK maps).

Certainly surface T anomalies move *away* from being directly predictable from precipitation during the course of a dry spell, but what they exactly converge *to* is less clear.

A concept of field capacity for drought dry-down

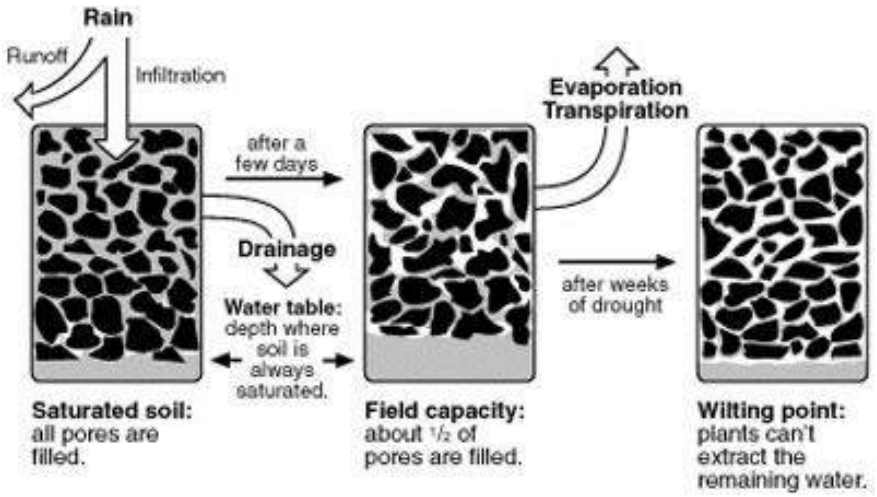
"*After heavy rain, a surface T anomaly map looks exactly like a precipitation anomaly map, but after a while it looks like a soil map*" (E. Blyth, CEH): how true is this?

Saturation

Field Capacity

Management Allowable Depletion

Permanent Wilting Point



Draw an analogy with the concept of field capacity in soil physics, which is defined as a point marking a transition from drainage dominated by *gravitational processes* to drainage dominated by *capillarity*.

A concept of field capacity for drought dry-down

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It's fairly common sense to suggest that during the first, say X, days of a dry spell dry-down will be dominated by climatological processes as the precipitation drains out of the surface, and thereafter evaporation and other land-atmosphere interactions will be controlled instead by soil and topographical variables (perhaps X is globally approx. 2 days as for field capacity, but perhaps not).

The implication of this is that in drought studies the concept of drought-as-precipitation-deficit ("climatological drought") is less useful than other, non-climatological measures of drought, because after X days what is happening at the land surface has much less to do with the atmosphere: after a certain amount of dry-down, the surface environment 'decouples' from the atmosphere.

Recent work at CEH in this area:

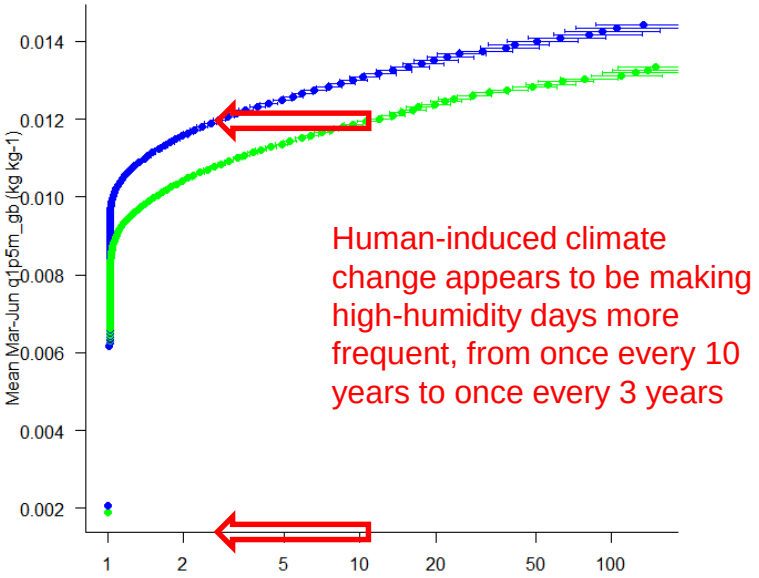
- Folwell et al (2015) "Large-scale surface responses during European dry spells diagnosed from land surface temperature", *J. Hydromet*., 17(3), 975-993, doi:10.1175/jhm-d-15-0064.1
- Gallego-Elvira et al. (2016) "Global observational diagnosis of soil moisture control on the land surface energy balance", *Geophys. Res. Lett.,* 43, doi:10.1002/2016GL068178
- Harris et al. (2017) "An evaluation of modelled evaporation regimes in Europe using observed dry spell land surface temperature", *J. Hydromet.,* doi:10.1175/JHM-D-16-0227.1
- Alberto Martinez de la Torre's talk about 10 day dry-down curves on Monday (see also http://jules.jchmr.org/sites/jules.jchmr.org/files/Talk_5_evaluation_4_Martinez.pdf).

Probabilistic Event Attribution (PEA)

We have used PEA techniques to estimate the human contribution to observed changes (Allen 2003, *Nature*), which involves an ensemble approach to estimating the uncertainty in the response of the climate system to external forcing. We used **two ensembles**:

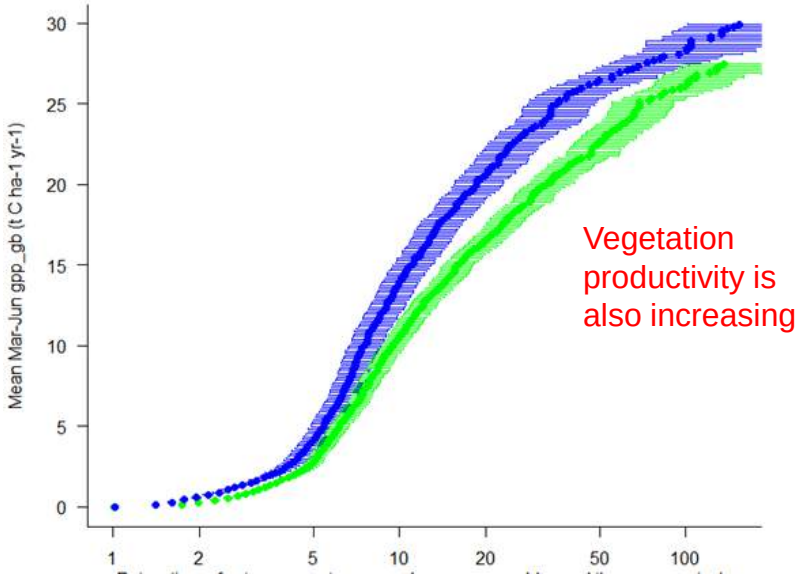
- One ***factual*** using climate data that describes the real climate of 2014
- One ***counterfactual*** using an atmosphere without human greenhouse gas emissions.

Specific humidity



Return time of extreme event (years)

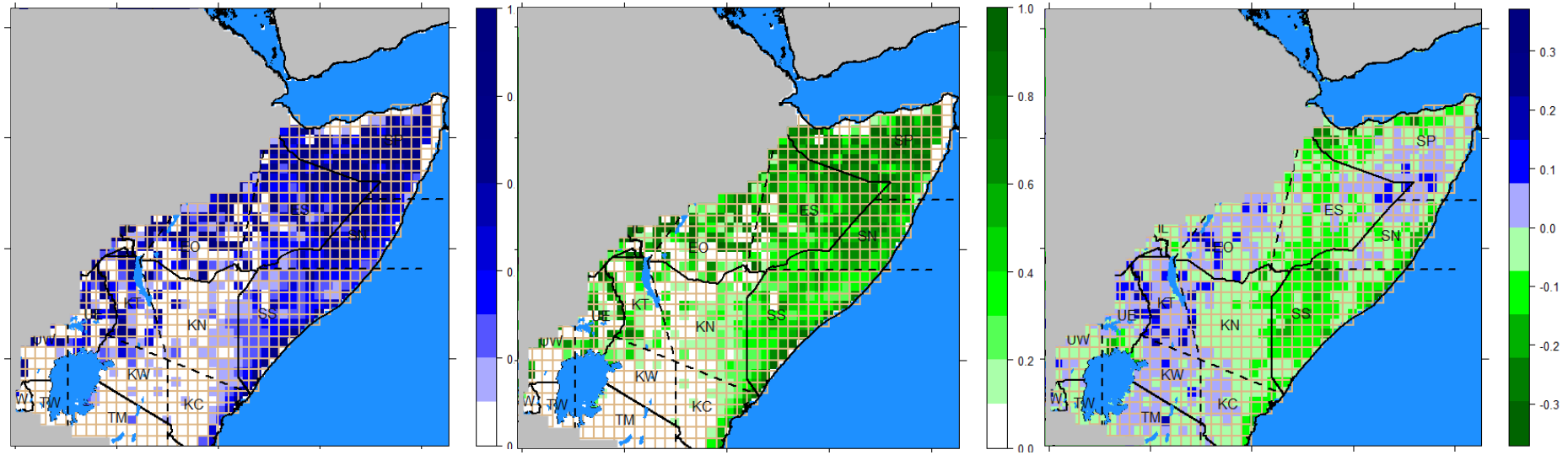
Gross Primary Productivity (*GPP*)



Return time (years)

Results

Climatological drought areas during the East African Long Rains season 2014 (all maps are averages over the March-May season). Here, drought is defined by the Standardised Precipitation Index *SPI* being more than 1.0 standard deviation lower than the long-term mean (the standard level for “moderately dry or drier” environments, WMO 2012), calculated from the regional climate model HadRM3P.

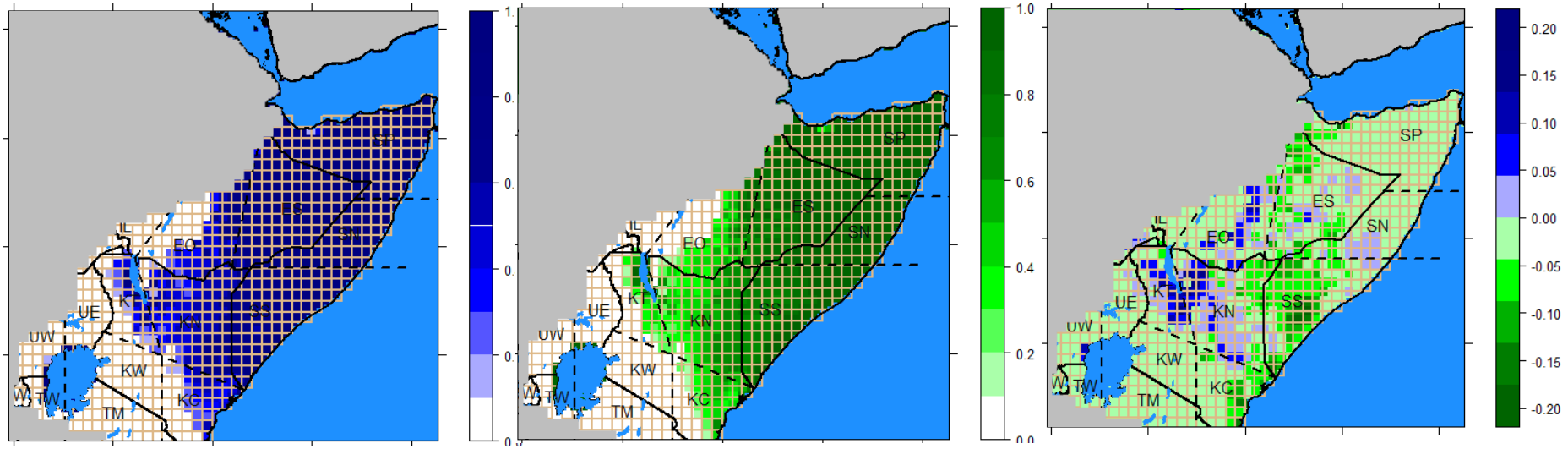


LEFT and CENTRE: coloured areas show high probabilities of drought (blue=factual ensemble mean, green=counterfactual). RIGHT: blue areas show areas where more drought is found under our simulations of actual 2014 conditions than found in our counterfactual simulations.

Climatological drought risk seems to be increasing in W Kenya, Uganda and NE Somalia but *de*creasing in the agricultural heartland of SW Somalia and eastern Kenya.

Results

Land surface drought areas during the East African Long Rains season 2014 (all maps are averages over the March-May season). Here, drought is defined by actual evapotranspiration (*ET*) being <1 mm/day, calculated from the land surface model JULES.



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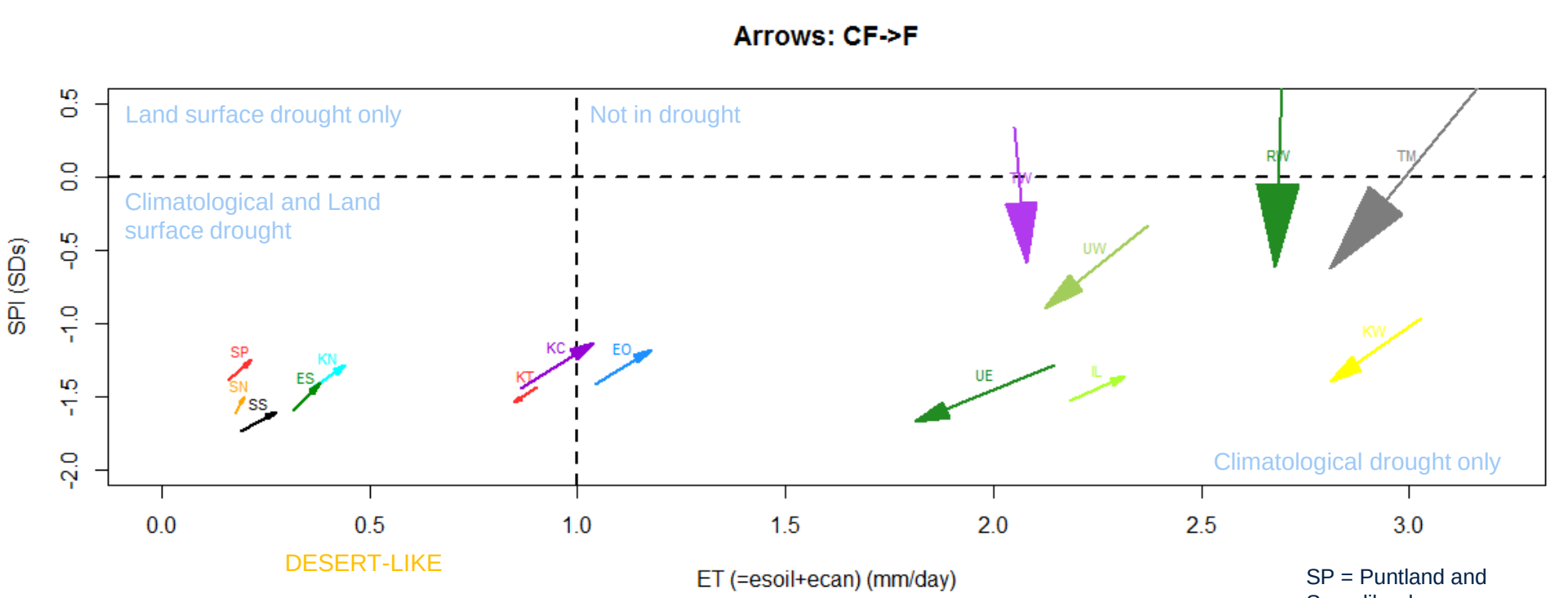
Land surface drought risk seems to be increasing in NW Kenya but *de*creasing in SW Somalia, but the distribution is not the same as for climatological drought.



- A state-space plot. Arrows run from counterfactual (the world without climate change) to factual (the world as it is) ensemble means, so the arrows indicate our best estimate of the effects of human-induced climate change in the GHoA in 2014.
- Permanently arid regions (deserts) usually have evapotranspiration (*ET*) <1 mm/day and have SPI close to zero, but this is not climatological drought in terms of SPI because precipitation levels are already minimal.
- What would happen to a non-desert gridcell if it suddenly experienced very low rainfall? SPI would decrease and ET would initially increase, but after a while the available water in the soil column will decrease and then ET rates will drop.
- Instead, what if rainfall increased, but became more episodic? In these sandy soils, large amounts of water will simply drain through to groundwater recharge, with the odd effect that increased rainfall can lead to reduced ET.

SP = Puntland and Somaliland
SN = Somalia north of Mogadishu
SS = Southern Somalia
EO = Ethiopia/Oromia
ES = Ethiopia/Somali
IL = the Ilemi Triangle
KN = Kenya NE
KT = Kenya NW (Turkana)
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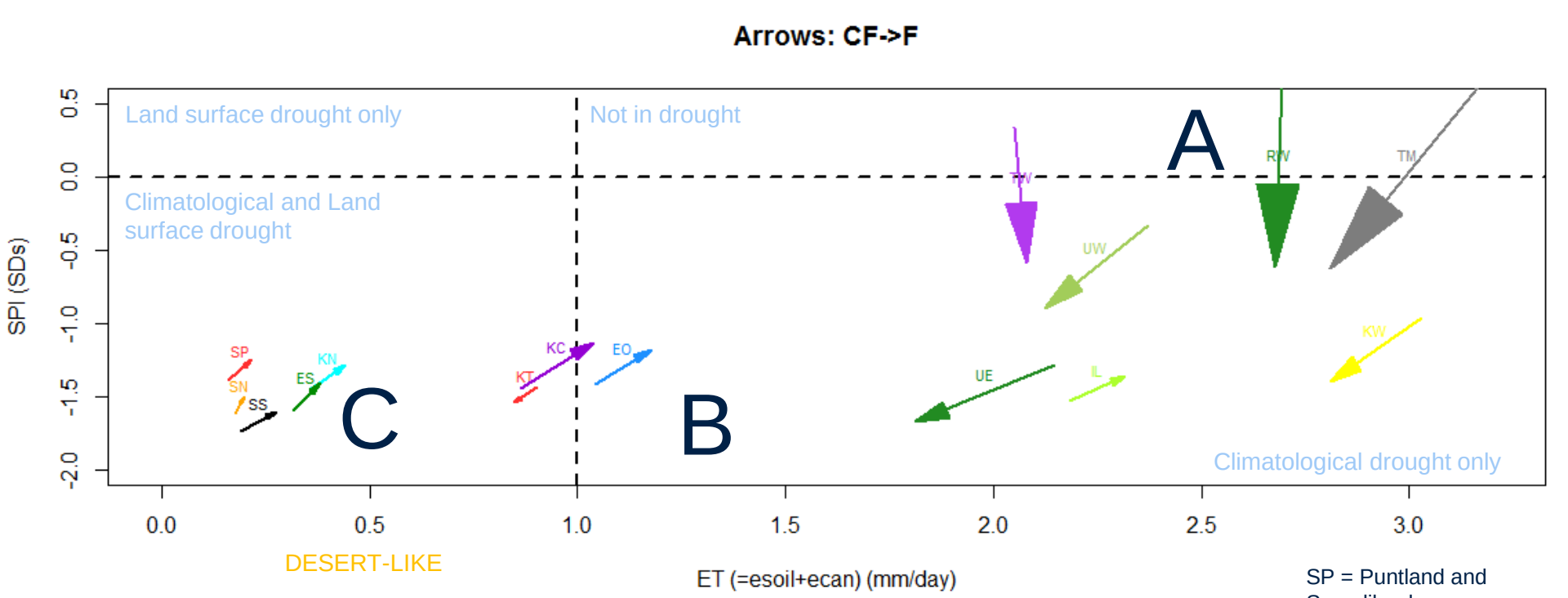

The trajectories for my study regions, grouped into three 'drought trajectories':

•Trajectory A: an attributable worsening of drought for the Lake Victoria part of the zone as a result of human-induced climate change. For Rwanda and Tanzania precipitation is decreasing (only), but for Uganda and western Kenya the land surface water balance is degrading also in terms of evaporation rates.

•Trajectory B: An attributable drift *slightly out* of drought for Kenya Coast and Oromia as a result of human-induced climate change

•Trajectory C: Drought status in E. Ethiopia, N. Kenya and N. Somalia broadly unaffected by climate change (if anything, getting slightly *better*). This is contrary to the current story of worsening drought in this region, implying that water scarcity in the GHoA may have much to do with other causes (e.g. conflict).

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A new global analysis of annual land-atmosphere hotspots

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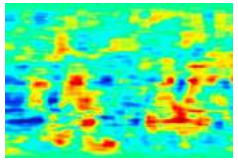
DP1: Ozone and crops

DP2: Water and food stress

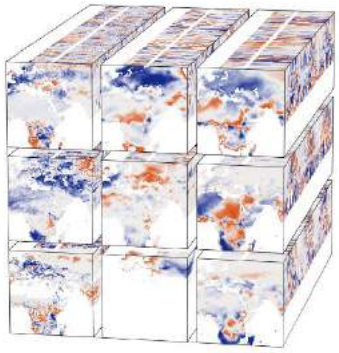
DP3: Ecosystem vulnerability

DP4: Greenhouse gases



Biosphere-Atmosphere Society index (BASi)

Calculate all data products operationally using the MPI's Earth System Data Cube



http://www.ileaps.org/biosphere-atmosphere-society-index

Max Planck Institute for Biogeochemistry

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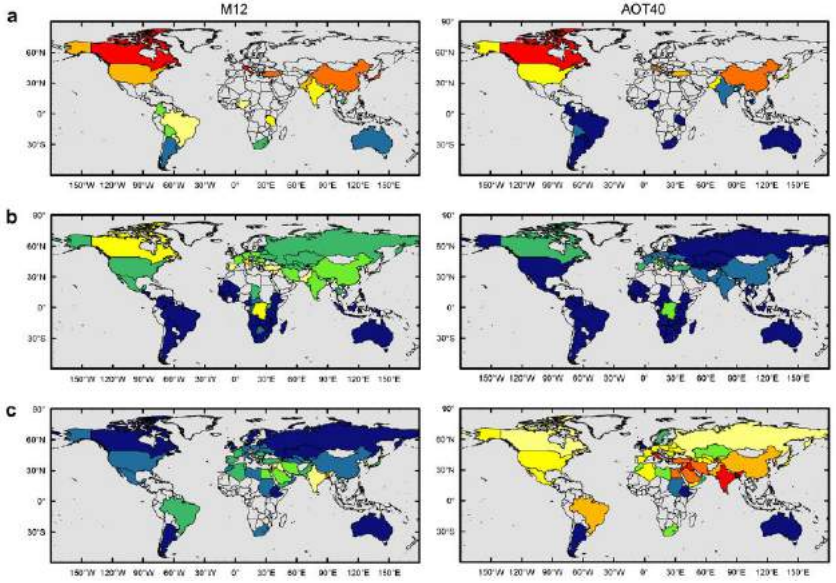
Data product 1: OZONE AND CROPS

"Impact of ozone on crop and forest productivity – *coincidence of EO-derived ozone levels with where and when the crops are most vulnerable to damage*"

Earth System Data Cube currently has total column ozone product only, but we need a surface (or at least tropospheric) ozone column product (e.g. NCEO's).

Model studies of the impact of ozone on crop production and how these impacts will change into the future: van Dingenen et al., 2009; Avnery et al., 2011a, 2011b; Tai et al., 2014.



National Relative Yield Loss (%)

0 2 4 6 8 10 15 20 25 30

Fig. 4. National relative yield loss according to the M12 (left panels) and AOT40 (right panels) metrics for (a) soybean, (b) maize, and (c) wheat.

From: Avnery et al., 2011a

Data product 2: WATER and FOOD STRESS

"Impact of water stress on crop and forest productivity – *coincidence of EO-derived low soil moisture levels with where and when the crops are most vulnerable to damage*"

Perhaps a simple combination of a water stress index and a reduction in productivity below a predefined level.

Related to Future Earth's Water, Food and Energy Nexus http://futureearth.org/future-earth-water-energy-food-nexus.

Data product 3: ECOSYSTEM VULNERABILITY

"Changes in vulnerable ecosystems – *changes in the metric of biogeochemical shifts and vegetation structural changes (Heyder et al. 2011) that quantifies ecosystem state in the arctic and the semi-arid regions*"

Heyder et al., 2011: Risk of severe climate change impact on the terrestrial biosphere. Environ. Res. Lett., 6, 034036.

A global hotspots map highlighting vulnerability, possibly spatially-restricted to a pre-defined global set of 'marginal ecosystems'.

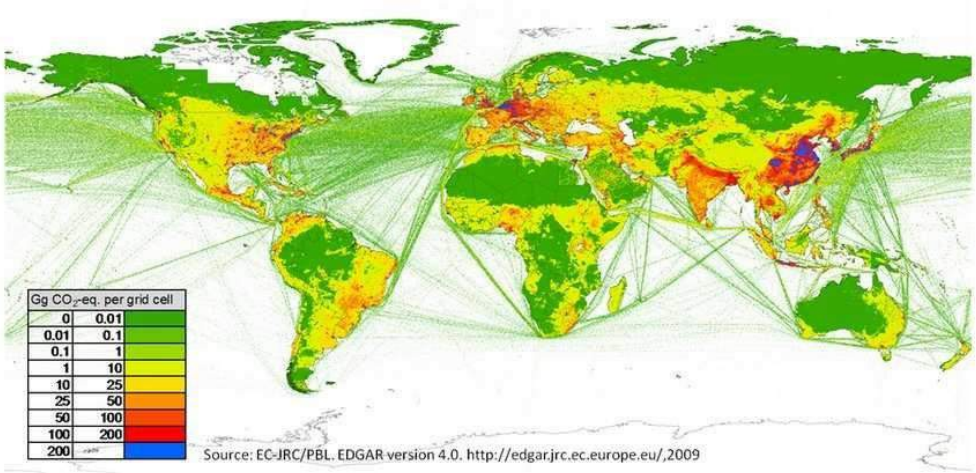
My current focus is on this data product: vulnerability in terms of water cycle variables (Greater Horn of Africa data), which are globally the most widely available.

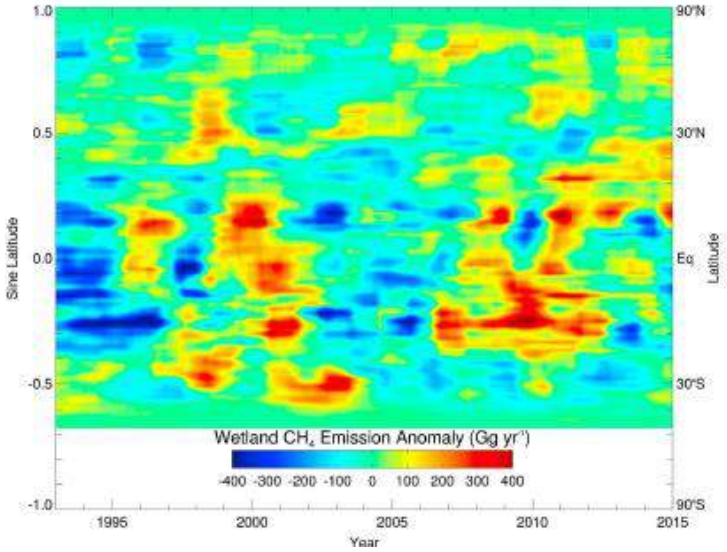
Data product 4: GREENHOUSE GASES

"Changes in greenhouse gas emissions – *methane, N_2O and CO_2 emissions from models driven by observed global weather patterns*"

Example of methane from wetlands: combine EO data on drivers (e.g., temperature, precipitation) with atmospheric column CH_4 measurements (from ESA CCI Greenhouse Gas project: http://www.esa-ghg-cci.org/).

Existing EDGAR data goes up to 2010.





Anomaly in modelled methane emissions from wetlands (McNorton … Hayman, …, Marthews et al. (2016, *GRL*)

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A new global analysis of annual land-atmosphere hotspots

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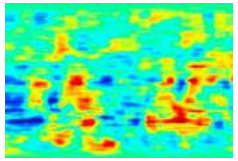

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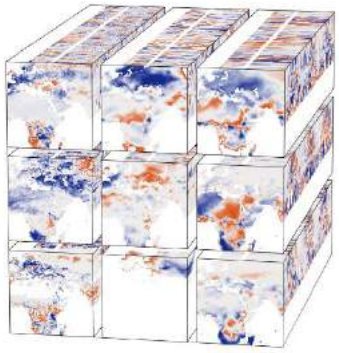

http://www.ileaps.org/biosphere-atmosphere-society-index

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The Biosphere-Atmosphere Society index (BASi)

iLEAPS/ESA index to summarise "**the major directions of biospheric and climatic co-variability, including fire, soil water stress, evapotranspiration, photosynthesis, crop productivity and land use change**".

See http://www.ileaps.org/biosphere-atmosphere-society-index .

Can be combined with other satellite-derived products (e.g. land cover maps) and model outputs from the land-surface modelling community (e.g. Land Model Intercomparison Project LandMIP).

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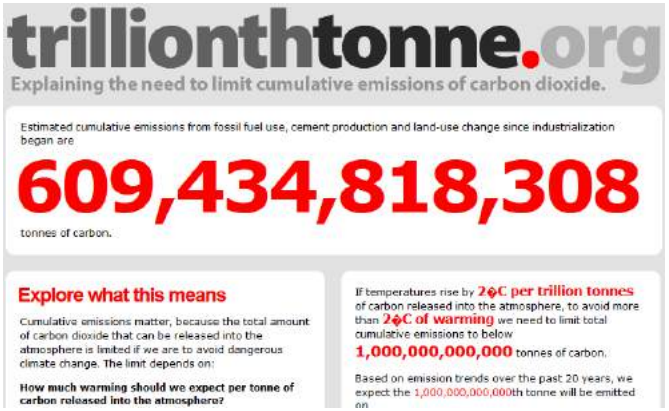
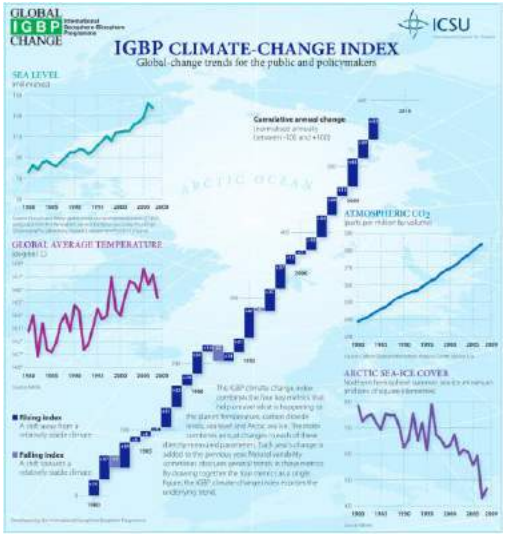
What will BASi look like?

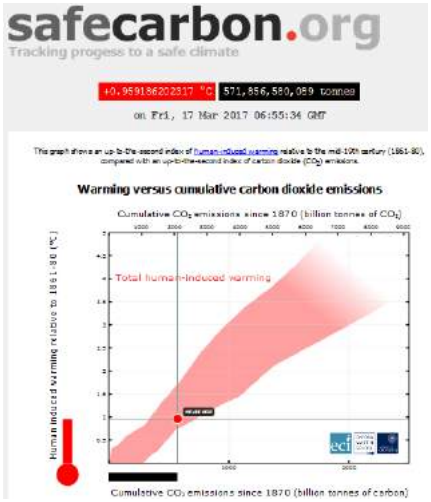
Final index will be calculated regularly and made available through the iLEAPS website http://www.ileaps.org/ .

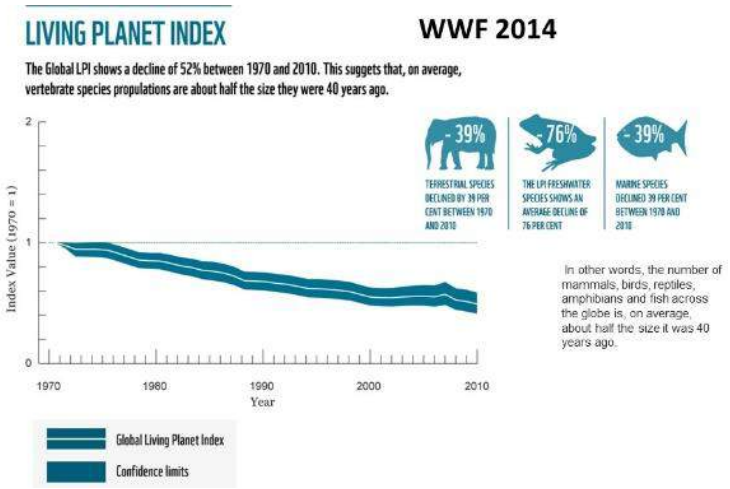
Similar existing indices: SafeCarbon, the IGBP Climate-Change Index, the WWF Living Planet Index, the annual Global Carbon Project's budgets and indices, Trillionth Tonne and many more.

Please come to the ESDC meeting tomorrow to know more (in your programme, Wed 10am-1pm).









Conclusions

In this study we asked whether human-induced climate change has played any role in the 2014 drought in the GHoA. We have shown that:

• Drought risk is progressively changing across the Horn of Africa region and that some of this is indeed attributable to anthropogenic climate change.

• However, regional patterns differ (greatly!) and we have identified three different ‘trajectories’ according to the differing impacts of anthropogenic climate change.

• The paradigm presented here can be reformulated in terms of an index and, with data availability from the ESDC, scaled up to a global data product with application far beyond the Horn of Africa.

Thank you very much

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Oxford, 12th September 2017

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